TRD 009 PA

APPARATUS AND METHODS FOR ENHANCING ELECTRONIC AUDIO SIGNALS

FIELD OF THE INVENTION

The present invention relates to the enhancement of electronic audio signals to improve the quality of sound produced from those signals, and more particularly to an apparatus and method for harmonically enhancing an electronic audio signal without the use of an active circuit element.

BACKGROUND OF THE INVENTION

It is usually considered more pleasurable to hear music, singing or other such complex sounds live, rather than hearing the same sound after it has been converted into an electronic audio signal and re-converted back into audible sound.

Many of the sounds we hear, especially musical notes, are often a composite. For example, a musical note having a basic pitch or fundamental frequency, usually contains components of the fundamental frequency called harmonics. These harmonics create the tonal quality or timbre of the sound, such as a musical note, that is often unique to the musical instrument or other sound producing source. In other words, these harmonics enrich the sound we hear. Numerous sound reproduction systems have been developed in an attempt to add harmonic enhancement to audio signals. However, these systems are often very sophisticated and expensive and the sound quality produced with such systems still falls short of the perceived quality of the original sound heard live.

A relatively unsophisticated and inexpensive system has been developed which produces an enhanced electronic audio signal which, when converted into audible sound, exhibits an improved harmonic quality compared to that of the original input audio signal and has been perceived as more closely duplicating the experience of hearing the original live sound in an acoustically designed environment. This system is disclosed in U.S. Patent No. 5,361,306, which is assigned to the assignee of the present application. The exemplary circuits disclosed in

the 5,361,306 patent include an input stage having a field inducing coil and an output stage having an electromagnetic field receptor (e.g., another coil) and an output. Input audio signals are transmitted through the inducing coil to set-up an electromagnetic field. The field inducing coil and the electromagnetic field receptor are weakly coupled such that when an input audio signal is transmitted through the field inducing coil, an enhanced audio signal is available at the output.

The present invention is an improvement to the inventions disclosed in the 5,361,306 patent. The present invention has a less complicated structure and is less expensive.

SUMMARY OF THE INVENTION

In accordance with the present invention, a number of methods and apparatus are provided for simply and inexpensively enhancing an electronic audio signal in such a way that the quality of audible sound produced from the audio signal more closely approaches that of the original sound heard live in an acoustically designed environment. Sound produced from an audio signal enhanced in accordance with the present invention appears to resist degradation at high volumes and tends to eliminate, or at least significantly reduce, the formation of sweet spots. It is desirable for a circuit according to the present invention to be geared toward restoring the perception of harmonics that are normally lost due to the limitations of audio conversion equipment, the recording process, shortcomings of the recording media and/or the like.

In one aspect of the present invention, an apparatus is provided for enhancing the quality of an input audio signal made up of frequency components within a band of frequencies having a low end and a high end. An apparatus, according to the principles of the present invention, includes a passive circuit that causes such an input audio signal, transmitted therethrough, to be distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal. This distortion is a non-linear amplification of frequency components of the input audio signal. The amplification is varied in such a manner that the

human ear is able to better perceive or pick up and register the harmonic character of the audio signal.

In a first embodiment of the present invention, the amplification of the frequency components in the input audio signal increases as the frequency components increase in frequency from an intermediate frequency up to a peak high frequency. The intermediate frequency may also be referred to as a reference frequency. Above the peak high frequency, it may be desirable for the amplification to decrease as the frequency components increase in frequency from the peak high frequency to the high end frequency. Instead of the peak high frequency being a single frequency, it may be desirable for the peak high frequency to be a range of frequencies such that the frequency components falling within the range have generally the same amplitude. The peak high frequency may be in the range of from about 6 KHz to about 30 KHz. Amplification of the frequency component(s) at the peak high frequency may be from about 1.5 times to about 3.0 times the amplification of an intermediate frequency component.

In a second embodiment of the present invention, the amplification of the frequency components in the input audio signal increases as the frequency components increase in frequency from a first intermediate frequency up to a peak high frequency and decrease in frequency from a second intermediate frequency down to a peak low frequency. The first and second intermediate frequencies may be referred to as first and second reference frequencies. The first and second intermediate frequencies may be the same frequency or different frequencies. Above the peak high frequency, it may be desirable for the amplification to decrease as the frequency components increase in frequency from the peak high frequency to the high end frequency. Below the peak low frequency, it may be desirable for the amplification to decrease as the frequency components decrease in frequency from the peak low frequency down to the low end frequency.

Instead of each being a single frequency, it may be desirable for the peak high frequency, the peak low frequency or both to be a range of frequencies such that frequency components falling within each range have generally the same amplitude. The peak high frequency may be in the range of from about 6 KHz to about 30 KHz. Amplification of the frequency component(s)

at the peak high frequency may be from about 1.5 times to about 3.0 times the amplification of the first intermediate frequency component. The peak low frequency may be in the range of from about 20 Hz to about 1 KHz. Amplification of the frequency component(s) at the peak low frequency may be from about 1.25 times to about 2.0 times the amplification of the second intermediate frequency component.

In accordance with a first embodiment of the present invention, the passive circuit may comprise a single transformer for non-linearly amplifying frequency components of the input audio signal such that the amplification of the frequency components in the input audio signal is increased as the frequency components increase in frequency from an intermediate frequency up to a peak high frequency. The distortion effected by the single transformer may also described in the following equivalent manner. The single transformer amplifies frequency components of the input audio signal such that the frequency components in the input audio signal increase in amplitude as the frequency components increase in frequency from an intermediate frequency up to a peak high frequency.

In accordance with a second embodiment of the present invention, the passive circuit may comprise first and second transformers for non-linearly amplifying frequency components of the input audio signal such that the amplification of the frequency components in the input audio signal increases as the frequency components increase in frequency from a first intermediate frequency up to a peak high frequency and decrease in frequency from a second intermediate frequency down to a peak low frequency. The distortion effected by the first and second transformers may also be described in the following equivalent manner. The first and second transformers amplify frequency components of the input audio signal such that the frequency components in the input audio signal increase in amplitude as the frequency components increase in frequency from a first intermediate frequency up to a peak high frequency and decrease in frequency from a second intermediate frequency down to a peak low frequency. The first and the second intermediate frequencies may be the same frequency or different frequencies.

In accordance with a second aspect of the present invention, an audio system is provided comprising an audio source, an audio amplifier and a passive circuit. The audio source generates

an input audio signal made up of frequency components within a band of frequencies having a high end and a low end. The audio amplifier generates a speaker drive signal. The passive circuit couples the input audio signal to the audio amplifier and distorts the input audio signal, when transmitted therethrough, into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the input audio signal.

It is desirable that no active elements be coupled between the audio source and the audio amplifier.

The passive circuit may comprise a single transformer which effects amplitude distortion of the input signal as defined by a first portion of a frequency response curve. The first portion of the curve increases non-linearly from an intermediate frequency up to a peak high frequency. Alternatively, the passive circuit may comprise first and second transformers which effect amplitude distortion of the input signal as defined by first and second portions of a frequency response curve. The first portion of the curve increases non-linearly from a first intermediate frequency up to a peak high frequency. The second curve portion increases non-linearly from a second intermediate frequency down to a peak low frequency. The first and second intermediate frequencies may be the same frequency or different frequencies.

In accordance with a third aspect of the present invention, a method is provided for enhancing the quality of electronic audio signals. The method comprises the steps of providing an input audio signal made up of frequency components within a frequency band having a high end and a low end, and distorting the input audio signal into an enhanced audio signal by passing the input audio signal through a passive circuit to amplify frequency components of the input signal. In accordance with one embodiment of the present invention, the amplification of the frequency components in the input audio signal increases as the frequency components increase in frequency from an intermediate frequency up to a peak high frequency. In accordance with another embodiment of the present invention, the amplification of the frequency components in the input audio signal increases as the frequency components increase in frequency from a first intermediate frequency up to a peak high frequency and decrease in frequency from a second

intermediate frequency down to a peak low frequency. The first and second intermediate frequencies may be the same frequency or different frequencies.

The present method can include the step of processing one or more of the enhanced audio signals into sound. The scope of the present invention is intended to include the sound that is so produced. The present enhanced audio signal and the sound produced therefrom includes audio signals and sounds having frequency components which fall within the range of normal human hearing (i.e., approximately 20 Hz to 20KHz).

The present method can also include the step of transmitting one or more audio signals, enhanced according to the present invention, from one location to another. The present method can further include the step of recording one or more of the present enhanced audio signals onto a recording medium. The scope of the present invention is also intended to include the recording medium having one or more of the present enhanced audio signals recorded thereon. The recording medium can be a magnetic recording medium (e.g., reel-to-reel tape, cassette tape, magnetic disk, etc.) or an optical recording medium (e.g, compact disk, video disk, etc.). The present invention is not intended to be limited to any particular type of recording medium or method of recording thereon.

The present invention provides an apparatus and method for enhancing the harmonic quality of an electronic audio signal, in particular an audio signal having a complex wave form (i.e., multiple frequency components such as, for example, music, singing, speech, animal sounds, naturally occurring sounds, equipment noises, and the like. An audio signal enhanced according to the present invention exhibits an improved harmonic quality compared to that of the input electronic audio signal. It has been found that a similar harmonic enhancement can be obtained using the circuits disclosed in U.S. Patent No. 5,361,306; U.S. Patent Application Serial No. 08/472,876, having a filing date of June 7, 1995 and entitled APPARATUS AND METHOD OF ENHANCING ELECTRONIC AUDIO SIGNALS; and U.S. Patent Application Serial No. 08/909,807, having a filing date of August 12, 1997 and entitled APPARATUS AND

METHODS FOR THE HARMONIC ENHANCEMENT OF ELECTRONIC AUDIO SIGNALS, the disclosures of which are incorporated herein by reference.

The present teachings and disclosure reveal that there are a variety of other ways of obtaining the same or a similar harmonic enhancement in an electronic audio signal. Having been provided with the teachings and the exemplary circuits disclosed herein, it will be a matter of simple trial and error experimentation, if any, for one of ordinary skill in the art to design additional ways to produce the same or a similar enhancing effect. Accordingly, the general and specific circuits disclosed herein are examples only and the present invention is not intended to be so limited.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a transformer constructed in accordance with a first embodiment of the present invention;

Fig. 2 is a perspective view of the bobbin of the transformer illustrated in Fig. 1;

Fig. 3 is a view taken along view line 3-3 in Fig.1;

Fig. 4 is a schematic side view of the bobbin illustrated in Fig. 3;

Fig. 5 is a circuit diagram of a passive circuit constructed in accordance with a first embodiment of the present invention coupled to an audio signal source and an audio amplifier;

Fig. 6 is an exploded view of two E-core sections and two I-core sections of the core illustrated in Fig. 1;

Fig. 7 is an illustration of first, second and third frequency response curves generated by a passive circuit constructed in accordance with a first embodiment of the present invention;

Fig. 8 is a circuit diagram of a passive circuit constructed in accordance with a second embodiment of the present invention coupled to an audio source and an audio amplifier;

Fig. 9 is a perspective view of a first transformer constructed in accordance with a second embodiment of the present invention;

Fig. 10 is a perspective view of the bobbin of the transformer illustrated in Fig. 9;

Fig. 10A is a schematic side view of the bobbin illustrated in Fig.10;

Fig. 11 is a view taken along view line 11-11 in Fig. 9;

Fig. 12 is a perspective view of a second transformer constructed in accordance with a second embodiment of the present invention;

Fig. 13 is a perspective view of the bobbin of the transformer illustrated in Fig. 12;

Fig. 13A is a schematic side view of the bobbin illustrated in Fig.13;

Fig. 14 is a view taken along view line 14-14 in Fig. 12; and

Fig. 15 is an illustration of first, second and third frequency response curves generated by a passive circuit constructed in accordance with a second embodiment of the present invention;

DETAILED DESCRIPTION OF THE INVENTION

Although the present invention is herein described in terms of specific embodiments, it will be readily apparent to those skilled in this art that various modifications, re-arrangements, and substitutions can be made without departing from the spirit of the invention. The scope of the present invention is thus only limited by the claims appended hereto.

Each of the particular exemplary embodiments disclosed in the present application produces an enhancement of an electronic audio signal. An apparatus, according to the principles of the present invention, comprises a passive circuit capable of distorting an input audio signal transmitted therethrough by non-linearly (i.e., non-uniformly) amplifying enhancing harmonics or frequency components in the input audio signal. By increasing the amplitude of enhancing harmonics in this manner, the resulting enhanced audio signal exhibits an improved harmonic quality compared to that of the input audio signal.

The present circuit is operatively adapted to accomplish enhancement without using any active elements such as operational amplifiers, transistors, vacuum tubes, etc. Thus, the passive circuit does not add power to the input audio signal.

Exemplary Embodiment No. 1

A passive circuit 5 for enhancing an electronic audio signal, constructed in accordance with a first embodiment of the present invention, is illustrated in the circuit diagram of Fig. 5.

The circuit 5 comprises a single transformer 10. The transformer 10 includes a bobbin 20, a ferromagnetic core 30 and two magnetically coupled coils 40 and 42, see Figs. 1-3 and 5.

The bobbin 20 may be formed from a fiber reinforced polymeric material. In the illustrated embodiment, the bobbin 20 comprises a glass fiber reinforced nylon. The bobbin 20 has a substantially rectangular-shaped tubular portion 22 having a core-receiving aperture 22a extending through it. Provided at opposite ends of the tubular portion 22 are first and second flanges 24 and 26. The wall thickness of each of the tubular portion 22 and the flanges 24 and 26 is about .040 inch. The width W_F and length L_F of each flange 24 and 26 are about 1.48 inches and 1.54 inches respectively. The width W_A, height H_A and length L_A of the aperture 22a are about .765 inch, 1.02 inches, and .765 inch, respectively. Each of the flanges 24 and 26 includes a pin-containing portion 24a and 26a having six L-shaped pins embedded therein. The twelve pins are designated in the drawings P_1-P_{12}. One such bobbin is commercially available from Plastron Corporation under the product designation "94HB."

The first coil 40 is defined by first and second primary winding portions 40a and 40b which are connected in series, see Fig. 5. The second coil 42 is defined by first and second secondary winding portions 42a and 42b which are connected in series.

A first wire 44, a type "39single-poly-nylon(SPN)155°C" wire, wherein 39 is the wire gauge, SPN is the outer coating material, and 155°C is the wire temperature rating is randomly wound in a clockwise direction about the tubular portion 22 to form the first primary winding portion 40a. The winding portion 40a comprises 1000 turns and has a DC resistance of about 285 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_1 and P_3, see Figs. 2, 4 and 5. A first layer 51 of a fiber reinforced polymeric film is wrapped about the first primary winding portion 40a, see Fig. 3. In the illustrated embodiment, the film comprises a glass fiber reinforced polyester film having a thickness of about .0065 inch. Such a film is commercially available from TESA Inc. under the product designation "IL-4426." The first layer 51 has a thickness of about .0065 inch.

A second wire 48, a type "34SPN155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer 51 so as to form the first secondary winding portion 42a. The winding portion 42a comprises 2000 turns and has a DC resistance of about 156 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_7 and P_9. A second layer 53 of the fiber reinforced polymeric film described above is wrapped about first secondary winding portion 42a, see Fig. 3. The second layer 53 has a thickness of about .013 inch.

A third wire 50, a type "39SPN155°C" wire, is randomly wound in a clockwise direction about the second film layer 53 so as to form the second primary winding portion 40b. The winding portion 40b comprises 1000 turns and has a DC resistance of about 335 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_3 and P_6. A third layer 55 of the fiber reinforced polymeric film is wrapped about second primary winding portion 40b, see Fig. 3. The third layer 55 has a thickness of about .013 inch. The first and second primary winding portions 40a and 40b are connected in series via pin P_3 so as to define the first coil 40 extending between pins P_1 and P_6.

A fourth wire 52, a type "34SPN155°C" wire, is randomly wound in a counter-clockwise direction about the third film layer 55 so as to form the second secondary winding portion 42b. The winding portion 42b comprises 2000 turns and has a DC resistance of about 186 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_9 and P_{11}. A fourth layer 57 of the fiber reinforced polymeric film is wrapped about second secondary winding 42b. The fourth layer 57 has a thickness of about .0065 inch. The first and second secondary winding portions 42a and 42b are connected in series via pin P_9 so as to define the second coil 42 extending between pins P_7 and P_{11}.

The first, second, third and fourth wires 44, 48, 50 and 52 are commercially available from the Phelps Dodge Corporation.

The core 30 is formed from numerous E-core and I-core sections 32 and 34, see Figs. 1, 3 and 6. The sections 32 and 34 comprise a ferromagnetic material, such as a 24 gauge, M50 grade steel. The sections 32 and 34 are assembled by stacking the E-core and I-core sections 32

and 34 alternatively so that each I-core section 34 lies between adjacent E-core sections 32, see Fig. 6. A single I-core section 34 may be laminated to each E-core section 32 before assembly. Center portions 32a of the E-core sections 32 fill the core-receiving aperture 22a of the bobbin 20. After assembly, the sections 32 and 34 are laminated to one another by coating the outer surfaces of the assembled sections 32 and 34 with a varnish. Such a varnish is commercially available from P.D. George Co. under the product designation "77X010." In the illustrated embodiment, each E-core section 32 has a thickness of about .025 inch. Each I-core section 34 has a thickness of about .025 inch. The length L_C of the core 30 is about 2.25 inches, the thickness T_C of the core 30 is about .750 inch, and the height H_C of the core 30 is about 1.875 inch, see Fig. 1.

The primary winding portions 40a and 40b are interleaved with the secondary winding portions 42a and 42b so as to achieve a high degree of coupling between the primary winding portions 40a, 40b and the secondary winding portions 42a, 42b as well as to minimize the capacitance between the winding portions 40a, 40b and 42a, 42b. The transformer 10 is designed with very low flux density to increase the ability of the transformer 10 to accept low level audio signals, increase primary inductance, decrease capacitive reactance and increase the overall frequency response of the circuit 5.

The passive circuit 5 is intended to be coupled directly to an audio signal source S, such as a CD player, a laser disc player, a tape player, a radio, a digital audio tape (DAT) player, and to an audio amplifier A, such as a a preamplification stage, e.g., a solid state or vacuum tube preamplifier, or a power amplification stage, e.g., an integrated power amplifier, a vacuum tube power amplifier, a solid state power amplifier or a hybrid power amplifier. Any commercially available connector(s) may be used to connect the passive circuit 5 to the signal source including a single-ended connector or a balanced connector. No active element is connected between the source S and the audio amplifier A, see Fig. 5. It has been found that when the transformer 10 is coupled in this manner and an input audio signal made up of frequency components within a band of frequencies having a low end and a high end is transmitted through the transformer 10,

the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal. This distortion is a non-linear amplification of at least a portion of the frequency components of the input audio signal. The amplification is preferably varied in a such manner that the human ear is able to better perceive or pick up and register the harmonic character of the audio signal. For example, the frequency components near the high end of the band of frequencies may be amplified by an amount which exceeds the amount by which intermediate frequency components between the low and high ends of the band of frequencies are amplified.

In Fig. 7, first, second and third exemplary frequency response curves C_1, C_2, C_3, generated by a passive circuit 5 constructed in accordance with the illustrated embodiment described above, are shown. For each curve, output voltages are plotted versus frequency for normalized input audio signals. The frequency response curves C_1, C_2, C_3 were obtained by connecting the first coil 40 of the transformer 10 to a signal source S, a conventional signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22 KHz and connecting the second coil 42 of the transformer 10 to resistive loads of 20 KOHMS (Curve C_1), 50 KOHMS (Curve C_2), and 100 KOHMS (Curve C_3), which loads represented equivalent impedances that the transformer 10 might see when connected to the inputs of conventional audio amplifiers. No active element was interposed between the input source S and any one of the resistive loads.

Each of the first, second and third curves C_1, C_2, C_3 represents the amplification that occurs to frequency components of an input audio signal when the input audio signal passes through the passive circuit 5 and the output (i.e., the second coil 42) of the passive circuit 5 is connected to a resistive load. The resistive load is 20 KOHMS for curve C_1, 50 KOHMS for curve C_2, and 100 KOHMS for curve C_3. From these three curves C_1, C_2, C_3, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 5. This distortion is a non-linear amplification of the frequency components of the input audio signal.

Specifically, the amplification of the frequency components of the input audio signal is substantially constant for intermediate frequency components falling within a band of frequencies of about 20 Hz to about 3.5 KHz and increases for frequency components increasing in frequency from about 3.5 KHz up to a peak high frequency of about 20 KHz. Above the peak high frequency of about 20 KHz, the amplification decreases as the frequency components increase in frequency from the peak high frequency of about 20 KHz to a high end frequency of about 22 KHz. The amplification or gain is between about 1.5 and 2.0 for the intermediate frequency components falling within the band of frequencies of about 20 Hz to about 5 KHz and is between about 2.6 and about 4.8 for frequency components at the peak high frequency. Hence, for Curve C_1, the amplification of the frequency component at the peak high frequency is about 1.5 times the average amplification of a range of intermediate frequency components from 20 Hz to 3.5 KHz. For Curve C_2, the amplification of the frequency component at the peak high frequency is about 2.0 times the average amplification of a range of intermediate frequency components from 20 Hz to 3.5 KHz. For Curve C_3, the amplification of the frequency component at the peak high frequency is about 2.3 ~~2.8~~ times the average amplification of a range of intermediate frequency components from 20 Hz to 3.5 KHz.

It is believed that the frequency response of the passive circuit 5 for a given load can be varied by changing one or more of the following: the number of turns of one or both of the coils 40 and 42; the size and type of wire used to make up the coils 40 and 42; the DC resistance of one or more of the first and second primary winding portions 40a and 40b and the first and second secondary winding portions 42a and 42b; the size of the core 30; and the gauge and grade of the material used to form the core 30. It is also believed that if the capacitance of the transformer 10 is varied, the amplification of the frequency components at the high end of the band of frequencies may be varied. Capacitance may be altered by changing the thickness of one or more of the film layers 51, 53 and 55; the DC resistance of one or more of the winding portions 40a, portions 40a, 42a, 40b and 42b; and/or the location of one or more of the winding portions 40a, 42a, 40b and 42b. Thus, an empirical determination is required to determine

exactly the make up of a transformer 10 in order to effect a desired frequency response when the transformer is coupled to a given load.

Thus, in accordance with a first embodiment of the present invention, an input audio signal is distorted into an enhanced audio signal by passing the input audio signal through a passive circuit 5 to amplify frequency components of the input signal. The amplification of the frequency components in the input audio signal increases as the frequency components increase in frequency from an intermediate frequency up to a peak high frequency. Above the peak high frequency, it is desirable for the amplification to decrease as the frequency components increase in frequency from the peak high frequency to the high end frequency.

It is further contemplated with regard to the first embodiment of the present invention that instead of the peak high frequency comprising a single frequency, it may be desirable for the peak high frequency to be a relatively narrow range of frequencies such that the frequency components falling within the narrow range have generally the same amplitude.

Curves C_1, C_2 and C_3 are provided for illustrative purposes only. It is believed that the amplification of intermediate frequency components, e.g., those of about 20 Hz to about 3.5 KHz, may be unity gain (1.0), less than 1.0 or greater than 1.0. The peak high frequency may be in the range of from about 6 KHz to about 30 KHz. Amplification of the frequency component(s) at the peak high frequency may be from about 1.5 times to about 3.0 times the amplification of intermediate frequency component of the average amplification of a range of intermediate frequency components.

It is further contemplated that the order of the winding portions 40a, 40b, 42a and 42b may vary so as to shield incoming electromagnetic interference (EMI) and radio frequency interference (RFI) radiation. Thus, the second wire 48 may be wound first on the tubular portion 22 in a counter-clockwise direction, followed by the first wire 44 which is wound in a clockwise direction, followed by the fourth wire 52 which is wound in a counter-clockwise direction, followed by the third wire 50 which is wound in a clockwise direction. Hence, the order of the winding portions is as follows: first secondary winding portion 42a followed by first primary winding portion 40a followed by second secondary winding portion 42b followed by second

primary winding portion 40b. The second primary winding portion 40b acts as a shield such that its own flux lines cancel most incoming EMI and RFI radiation.

Exemplary Embodiment No. 2

A passive circuit 300 comprising first and second transformers 100 and 200, constructed in accordance with a second embodiment of the present invention, is illustrated in the circuit diagram of Fig. 8. The first and second transformers 100 and 200 are constructed in essentially the same manner as the transformer 10 described above and are illustrated in Figs. 9, 10, 10A and 11 and 12, 13, 13A and 14. The first transformer 100 includes a bobbin 120, see Figs.10 and 10A, a ferromagnetic core 130, see Fig. 9, and two magnetically coupled coils 140 and 142, see Fig. 8. The second transformer 200 includes a bobbin 220, see Figs. 13 and 13A, a ferromagnetic core 230, see Fig. 12, and two magnetically coupled coils 240 and 242, see Fig. 8.

The bobbins 120 and 220 are constructed in essentially the same manner as bobbin 20 described above. In the illustrated embodiment, the bobbins 120 and 220 are formed from a glass fiber reinforced nylon.

The bobbin 120 has a substantially rectangular-shaped tubular portion 122 having a core-receiving aperture 122a extending through it. Provided at opposite ends of the tubular portion 122 are first and second flanges 124 and 126. The wall thickness of each of the tubular portion 122 and the flanges 124 and 126 is about .040 inch. The width W_F and length L_F of each flange 124 and 126 are about 1.23 inches and 1.34 inches, respectively. The width W_A, height H_A and length L_A of the aperture 122a are about .640 inch, .830 inch, and .640 inch, respectively. Each of the flanges 124 and 126 includes a pin-containing portion 124a and 126a having six L-shaped pins embedded therein. The twelve pins are designated in the drawings P_1-P_{12}.

The bobbin 220 has a substantially rectangular-shaped tubular portion 222 having a core-receiving aperture 222a extending through it. Provided at opposite ends of the tubular portion 222 are first and second flanges 224 and 226. The wall thickness of each of the tubular portion 222 and the flanges 224 and 226 is about .040 inch. The width W_F and length L_F of each flange

224 and 226 are about 1.48 inches and 1.54 inches, respectively. The width W_A, height H_A and length L_A of the aperture 222a are about .765 inch, 1.02 inches, and .765 inch, respectively. Each of the flanges 224 and 226 includes a pin-containing portion 224a and 226a having six L-shaped pins embedded therein. The twelve pins are designated in the drawings P_1-P_{12}.

The first coil 140 of the transformer 100 is defined by first and second primary winding portions 140a and 140b which are connected in series, see Fig. 8. The second coil 142 is defined by first and second secondary winding portions 142a and 142b which are connected in series.

A first wire 144, a type "39single-poly-nylon(SPN) 155°C" wire, is randomly wound in a clockwise direction about the tubular portion 122 to form the first primary winding portion 140a. The winding portion 140a comprises 500 turns and has a DC resistance of about 106 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_1 and P_3, see Figs. 8, 10, and 10A. A first layer 151 of a fiber reinforced polymeric film, such as the one discussed above with regard to the first embodiment of the present invention, is wrapped about the first primary winding portion 140a, see Fig. 11. The first layer 151 has a thickness of about .0065 inch.

A second wire 148, a type "32SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer 151 so as to form the first secondary winding portion 142a. The winding portion 142a comprises 1000 turns and has a DC resistance of about 46 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_7 and P_9. A second layer 153 of the fiber reinforced polymeric film is wrapped about first secondary winding portion 142a, see Fig. 11. The second layer 153 has a thickness of about .0065 inch.

A third wire 150, a type "39SPN 155°C" wire, is randomly wound in a clockwise direction about the second film layer 153 so as to form the second primary winding portion 140b. The wire 150 is soldered or otherwise connected to pin P_3, randomly wound about the second film layer 153 about 400 turns, and connected to pin P_5. In the illustrated embodiment, the third wire 150, after being connected to pin P_5, is randomly wound about the second film layer 153 another 100 turns and soldered or otherwise connected to pin P_6. In this embodiment, the winding portion 140b extends between pins P_3 and P_5, comprises 400 turns and has a DC

resistance of about 107 Ohms ± 10%. A third layer 155 of the fiber reinforced polymeric film is wrapped about second primary winding portion 140b. The third layer 155 has a thickness of about .0065 inch. The first and second primary winding portions 140a and 140b of the first transformer 100 are connected in series via pin P_3 so as to define the first coil 140 extending between pins P_1 and P_5.

A fourth wire 152, a type "34SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the third film layer 155 so as to form the second secondary winding portion 142b. The winding portion 142b comprises 1000 turns and has a DC resistance of about 58.0 Ohms ± 10%. It is soldered or otherwise connected to pins P_9 and P_{11}. A fourth layer 157 of the fiber reinforced polymeric film is wrapped about second secondary winding portion 142b. The fourth layer 157 has a thickness of about .0065 inch. The first and second secondary winding portions 142a and 142b of the first transformer 100 are connected in series via pin P_9 so as to define the second coil 142 extending between pins P_7 and P_{11}.

The wires 144, 148, 150 and 152 are commercially available from the Phelps Dodge Corporation.

The core 130 of the first transformer is formed from numerous E-core and I-core sections 132 and 134, see Figs. 9 and 11, in substantially the same manner as described above with regard to core 30. The sections 132 and 143 comprise a ferromagnetic material, such as a 29 gauge, M6 grade steel. In the illustrated embodiment, each E-core section 132 has a thickness of about .014 inch. Each I-core section 134 has a thickness of about .014 inch. The length L_C of the core 130 is about 1.875 inches, the thickness T_C of the core 130 is about .625 inch, and the height H_C of the core 130 is about 1.5625 inches, see Fig. 9.

The primary winding portions 140a and 140b are interleaved with the secondary winding portions 142a and 142b so as to achieve a high degree of coupling between the primary winding portions 140a, 140b and the secondary winding portions 142a, 142b as well as to minimize the capacitance between the winding portions 140a, 140b and 142a, 142b. The transformer 100 is designed with very low flux density to increase the ability of the circuit 300 to accept low level

audio signals, increase primary inductance, decrease capacitive reactance and increase the overall frequency response of the circuit 300.

The first coil 240 of the second transformer 200 is defined by first and second primary winding portions 240a and 240b which are connected in series, see Fig. 8. The second coil 242 is defined by first and second secondary winding portions 242a and 242b which are connected in series.

A first wire 244, a type "39single-poly-nylon(SPN)155°C" wire, is randomly wound in a clockwise direction about the tubular portion 222 of the bobbin 220 to form the first primary winding portion 240a. The winding portion 240a comprises 1000 turns and has a DC resistance of about 250 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_1 and P_3, see Figs. 8, 13 and 13A. A first layer 251 of a fiber reinforced polymeric film, such as the one used in the first embodiment described above, is wrapped about the first primary winding portion 240a. The first layer 251 has a thickness of about .0065 inch.

A second wire 248, a type "34SPN155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer 251 so as to form the first secondary winding portion 242a. The winding portion 242a comprises 2000 turns and has a DC resistance of about 156 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_7 and P_9. A second layer 253 of the fiber reinforced polymeric film is wrapped about first secondary winding portion 242a, see Fig. 14. The second layer has a thickness of about .0065 inch.

A third wire 250, a type "39SPN155°C" wire, is randomly wound in a clockwise direction about the second film layer 253 so as to form the second primary winding portion 240b. The wire 250 is soldered or otherwise connected to pin P_3, randomly wound about the second film layer 253 about 500 turns, and connected to pin P_5. In the illustrated embodiment, the third wire 250, after being connected to pin P_5, is randomly wound about the second film layer 253 another 500 turns and soldered or otherwise connected to pin P_6. In this embodiment, the winding portion 240b extends between pins P_3 and P_5, comprises 500 turns and has a DC resistance of about 150 Ohms $\pm$ 10%. A third layer 255 of the fiber reinforced polymeric film is

wrapped about second primary winding portion 240b. The third layer 225 has a thickness of about .0065 inch. The first and second primary winding portions 240a and 240b of the second transformer 200 are connected in series via pin P_3 so as to define the first coil 240 extending between pins P_1 and P_5.

A fourth wire 252, a type "34SPN155°C" wire, is randomly wound in a counter-clockwise direction about the third film layer 255 so as to form the second secondary winding portion 242b. The winding portion 242b comprises 2000 turns and has a DC resistance of about 186 Ohms ± 10%. It is soldered or otherwise connected to pins P_9 and P_{11}. A fourth layer 257 of the fiber reinforced polymeric film (not shown) is wrapped about the second secondary winding portion 242b. The fourth layer 257 has a thickness of about .0065 inch. The first and second secondary winding portions 242a and 242b of the second transformer 200 are connected in series via pin P_9 so as to define the second coil 242 extending between pins P_7 and P_{11}.

The wires 244, 248, 250 and 252 are commercially available from the Phelps Dodge Corporation.

The core 230 is formed from numerous E-core and I-core sections 232 and 234, see Figs. 12 and 14, in the same manner as core 30 described above. The sections 232 and 234 comprise a ferromagnetic material, such as a 29 gauge, M6 grade steel. In the illustrated embodiment, each E-core section 232 has a thickness of about .014 inch. Each I-core section 234 has a thickness of about .014 inch. The length L_C of the core 230 is about 2.25 inches, the thickness T_C of the core 230 is about .750 inch, and the height H_C of the core 230 is about 1.875 inches, see Fig. 1.

The primary winding portions 240a and 240b are interleaved with the secondary winding portions 242a and 242b so as to achieve a high degree of coupling between the primary winding portions 240a, 240b and the secondary winding portions 242a, 242b as well as to minimize the capacitance between the winding portions 240a, 240b and 242a, 242b. The transformer 200 is designed with very low flux density to increase the ability of the passive circuit 300 to accept low level audio signals, increase primary inductance, decrease capacitive reactance and increase the overall frequency response of the circuit 300.

The first and second transformers 100 and 200 are connected to one another in series, as illustrated in Fig. 8, to define the passive circuit 300. A first hook-up or jumper wire 301, a type 24 gauge (UL 1007) lead wire, is coupled to pin P_5 of the first transformer 100 and to pin P_5 of the second transformer 200 and a second hook-up wire 303, a type 24 gauge (UL 1007) lead wire wire, is coupled to pin P_7 of the second transformer 200 and pin P_7 of the first transformer 100. The 24 gauge lead wire is commercially available from Belden Corporation.

The input of the passive circuit 300 may be coupled directly to an audio signal source S, such as a CD player, a DAT player, a laser disc player, a tape player and the like, and the output of the passive circuit 300 may be coupled directly to an audio amplifier, such as a pre-amplifier stage or a power amplifier stage, see Fig. 8. Any commercially available connector(s) may be used to connect the passive circuit 300 to the signal source including a single-ended connector or a balanced connector. No active element is connected between the source S and the audio amplifier A. It has been found that when the transformers 100 and 200 are used in this manner, they interact with one another such that when an input audio signal is transmitted through them, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 15, first, second and third exemplary frequency response curves C_1, C_2, C_3, generated by a passive circuit 300 constructed in accordance with the second embodiment described above, are shown. For each curve, output voltages are plotted versus frequency for normalized input signals. The frequency response curves C_1, C_2, C_3 were obtained by connecting pins P_1 of the first and second transformers 100 and 200 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting pins P_{11} of the transformers 100 and 200 to resistive loads of 20 KOHMS (Curve C_1), 50 KOHMS (Curve C_2), and 100 KOHMS (Curve C_3), which loads represented equivalent impedances that the transformers 100 and 200 might see when connected to conventional audio amplifiers. No active element was interposed between the input source S and the resistive loads.

Each of the first, second and third curves C_1, C_2, C_3 represents the amplification that occurs to frequency components of an input audio signal when the input audio signal passes through the passive circuit 300 and the output of the passive circuit 300 is connected to a resistive load. The resistive load is 20 KOHMS for curve C_1, 50 KOHMS for curve C_2, and 100 KOHMS for curve C_3. From these three curves C_1, C_2, C_3, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 300. This distortion is a non-linear amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from an intermediate frequency (about 2.0 KHz for a 20 KOHMS load and between about 2.5 KHz and 3.5 KHz for 50 KOHMS and 100 KOHMS loads) to a peak high frequency (about 22 KHz for 20 KOHMS, 50 KOHMS and 100 KOHMS loads) and decrease in frequency from the intermediate frequency down to a peak low frequency (about 20 Hz for a 20 KOHMS load, about 800 Hz for a 50 KOHMS load and about 1000 Hz for a 100 KOHMS load). The amplification of the frequency components at the peak high frequency is from about 2.0 to about 3.4. The amplification of the frequency components at the peak low frequency is from about 1.9 to about 2.5. Hence, for Curve C_1, the amplification of the frequency component at the peak high frequency is about 1.8 times the amplification of the intermediate frequency component at 2 KHz and the amplification of the frequency component at the peak low_frequency is about 1.7 times the amplification of the intermediate frequency component at 2 KHz.. For Curve C_2, the amplification of the frequency component at the peak high frequency is about 1.8 times the amplification of the intermediate frequency component at 3 KHz and the amplification of the frequency component at the peak low frequency is about 1.3 times the amplification of the intermediate frequency component at 3 KHz . For Curve C_3, the amplification of the frequency component at the peak high frequency is about 1.8 times the amplification of the intermediate frequency component at 3.5 KHz and the amplification of the

frequency component at the peak low frequency is about 1.4 times the amplification of the intermediate frequency component at 3.5 KHz.

It is believed that the frequency response of the passive circuit 300 for a given load can be varied by changing one or more of the following: the number of turns of one or more of the coils 140, 142, 240, 242; the size and type of the wire used to make up one or more of the coils 140, 142, 240, 242; the DC resistance of one or more of the coils 140, 142, 240, 242; the shape and size of one or both of the cores 130 and 230; and the gauge and grade of the material used to form one or both of the cores 130 and 230. More specifically, the low end frequency response of the passive circuit 300 is controlled by factors such as: 1) the primary to secondary turns ratio (i.e., the ratio of the combined turns of the first coils 140 and 240 to the combined turns of the second coils 142 and 242); 2) the primary inductance which is controlled by the number of turns of the first and second coils 140, 142, 240, 242 and the gauge and grade of the material from which the cores 130 and 230 are made; 3) the DC resistance of the coils 140, 142, 240, 242, the size and type of wire used to make up the coils 140, 142, 240, 242, and the mean length of each turn of the coils 140, 142, 240, 242; and 4) the impedance of the signal source S and the load. The high end frequency response of the passive circuit 300 is controlled by factors such as: 1) the inter-windings capacitance, i.e., the capacitance between the first coils 140, 240 and the second coils 142 , 242; 2) the intra-windings capacitance, i.e., the capacitance between adjacent primary and secondary winding portions on each transformer 100 and 200; 3) primary and secondary winding portion placement; and 4) the impedance of the signal source S and the load.

It is also believed that if the capacitance of the transformer is varied, the amplification of the frequency components at the high end of the band of frequencies may be varied. Capacitance may be altered by changing the thickness of one or more of the film layers 151, 153, 155, 251, 253, 255; the DC resistance of one or more of the winding portions 140a, 142a, 140b, 142b, 240a, 242a, 240b, 242b and/or the location of one or more of the winding portions 140a, 142a, 140b, 142b, 240a, 242a, 240b, 242b. It is further believed that if the inductance of one or both of the transformers 100 and 200 is varied, the amplification of the frequency components at the low

end of the band of frequencies may be varied. Inductance can be altered by changing the combined turns of the first coils 140 and 240 and/or the gauge and grade of the material from which the cores 130 and 230 are made. Thus, an empirical evaluation is required to determine exactly the make up of the transformers 100 and 200 in order to effect a desired frequency response when the transformers 100 and 200 are coupled to a given load.

In accordance with a second embodiment of the present invention, an input audio signal is distorted into an enhanced audio signal by passing the input audio signal through a passive circuit 300 to amplify frequency components of the input signal. The amplification of the frequency components in the input audio signal increases as the frequency components increase in frequency from a first intermediate or reference frequency up to a peak high frequency and decrease in frequency from a second intermediate or reference frequency down to a peak low frequency. The first and second intermediate frequencies may be the same frequency or different frequencies. Above the peak high frequency, it may be desirable for the amplification to decrease as the frequency components increase in frequency from the peak high frequency to the high end frequency. Below the peak low frequency, it may be desirable for the amplification to decrease as the frequency components decrease in frequency from the peak low frequency down to the low end frequency.

It is further contemplated with regard to the second embodiment of the present invention that instead of each being a single frequency, it may be desirable for the peak high frequency, the peak low frequency or both to be a relatively narrow range of frequencies such that frequency components falling within each narrow range have generally the same amplitude.

The peak high frequency may be in the range of from about 6 KHz to about 30 KHz. Amplification of the frequency component(s) at the peak high frequency may be from about 1.5 times to about 3.0 times the amplification of a first intermediate frequency. The peak low frequency may be in the range of from about 20 Hz to about 1 KHz. Amplification of the frequency component(s) at the peak low frequency may be from about 1.25 times to about 2.0 times the amplification of a second intermediate frequency.

It is further contemplated with regard to the first and second embodiments of the present invention that one or more of the transformers 10, 100 and 200 may be tapped. Tapping may occur during the winding of any one of the first and second primary winding portions and the first and second secondary winding portions. After a predetermined number of turns of a winding portion have been wound about the bobbin but before the final number of turns have been formed, the wire being wound may be connected to another of the pins on the bobbin. In the illustrated embodiment, the first transformer is tapped. After the third wire 150 is randomly wound 400 times about the second film layer 153, it is wrapped or otherwise connected to pin P_5. Thereafter, the wire 150 is wound another 100 times and connected to pin P_6. If wire 301 is connected to pin P_5, the effective second primary winding portion 140b comprises 400 turns. Alternatively, if the wire 301 is connected to pin P_6, the effective second primary winding portion 140b comprises 500 turns. By changing the connection of the wire 301 from pin P_5 to pin P_6, the enhancement of the audio signal passing through the passive circuit 300 is changed.

An enhanced audio signal, according to the present invention, exhibits an improved harmonic quality compared to that of the original input audio signal. Additional advantages and modifications will readily appear to those skilled in the art. For instance, it may be desirable for two or more of the above described passive circuits, i.e., either two or more of the first passive circuits 5, two or more of the second passive circuits 300, or a combination of the two passive circuits 5 and 300, to be used in series.

Furthermore, when electronic audio signals from a compact disc of music and vocals were transmitted through the circuits of the present invention and the resulting enhanced electronic audio signals re-recorded onto a cassette tape using a consumer cassette player/recorder, the sound quality of the music and vocals produced from the recorded cassette tape was perceptibly better than the same music and vocals produced directly from the compact disc. This occurred even though the compact disc format is widely recognized as producing superior sound quality compared to the cassette tape format.

It is believed that the present invention can be used to enhance electronic audio signals from sound converting equipment, for example a hearing aid, a microphone or the like, before

being either recorded onto a recording medium (for example, magnetic tape or optical disk) or converted directly into acoustic sound or other sound impulses. It is also believed that an audio signal enhanced according to the present invention can be transmitted through the air or some other medium, for example, for television, radio, sonar, computer or cellular telephone use; can be transmitted through transmission lines, for example, for telephone, cable TV or computer use; can be converted directly into audible sound, for example, for use at a concert, a play, in a restaurant, or a bar; and that it can be used in any other application which includes an audio signal such as, for example, in distinguishing sonar images, etc.

It is further contemplated that the passive circuit may comprise a single transformer for non-linearly amplifying frequency components of an input audio signal such that the amplification of the frequency components in the input audio signal is increased as the frequency components decrease in frequency from an intermediate frequency e.g., about 3.5 KHz down to a peak low frequency. It is believed that amplification of frequency components from about 3.5 KHz to about 20 KHz may be unity gain (1.0), less than 1.0 or greater than 1.0. It is also believed that amplification of the frequency component at the peak low frequency may be about 1.25 times to about 2.0 times the amplification of an intermediate frequency component or the average amplification of a range of intermediate frequency components falling within the band of frequencies of 3.5 KHz to 20 KHz.

The present invention in its broader aspects is therefore not limited to the specific details, representative apparatus and method, and illustrative examples shown and described herein. Departures may be made from such details without departing from the spirit or scope of the general inventive concept of the present invention. Therefore, the scope of the invention should be limited only by the following claims and equivalents thereof.

What is claimed is: